same difficulties as Sir George Airy, I propose with your permission to offer a few explanations.

Sir G. Airy summarises his remarks under six heads, but I think two would have sufficed, viz. that the bridge was too big to please Sir George, and that the engineers were presumably incompetent. As to size, for example, Sir George considers the fact of the cantilever being "longer than the Cathedral by 175 feet is in itself enough to excite some fear," and even to "justify great alarm." But when I look for some justification for this bold statement I find that Sir George does not advance any reason whatever, nor make use in any way of his high mathematical attainments, but simply shifts the responsibility for this alarm on to the shoulders of the "citizens of London," asking, "would they feel themselves in perfect security? I think not; and I claim the same privilege of entertaining the sense of insecurity for the proposed Forth Bridge."

If Sir George had alleged that the stresses on the cantilever could not be calculated, or that the strength of the steel ties and struts could not be predicted, or that the cantilever could not be erected, I might have replied by publishing diagrams of stresses, results of experiments, and the names of the firms who have tendered for the work. I cannot, however, answer an argument based upon the supposed fears of the "citizens of London."

To prove that Sir George's criticisms imply a charge of incompetency on the part of the engineers, I need only point out that in one sentence he remarks that "experienced engineers must have known instances in which buildings have failed from want of consideration of buckling," and in another, that "there appears to be a fear of its occurrence in various parts of the bracket," when "the bridge will be ruined." Sir George's conclusions on this head are, however, as he fairly enough states, "made in the total absence of experiment or explanation," and in ignorance whether "a theory of buckling finds place in any of the books which treat of engineering." To assume, however, that an engineer is similarly ignorant, clearly amounts to a grave charge of incompetency. Again, how incompetent must the engineer be who required to be informed that the "horizontal action of the wind on the great projecting brackets depends not simply on the wind's pressure, but also on its leverage," or who neglected to provide for the consequent stresses. Yet Sir George does not hesitate to say in reference to this, that "in the proposed Forth bridge there is a risk of danger of the most serious kind, which may perhaps surpass all other dangers."

As Sir George in the whole of his letter does not produce a single figure or fact in support of his very serious charges, I must, in justice to Mr. Fowler and myself, explain that it was from no want of data. At Sir George's request he was furnished with every necessary detail for ascertaining the maximum stress on each member, and the factor of safety. I stated in the paper referred to by Sir George at the commencement of his letter, that under the combined action of an impossible rolling load of 3400 tons upon one span, and a hurricane of 56 lbs. per square foot, the maximum stress upon the steel would in no case exceed 7½ tons per square inch. Any useful criticism must be directed to prove that such load is not enough or that such stress is too great. Nothing can be decided by appeals to the citizens of London.

Sir George's remarks about what he terms "buckling," and the "total absence of experiment," I can hardly reconcile with his having read my paper, because I have there devoted six pages to the question of long struts, and have given the results of the most recent experiments on flexure by myself and others. When he asks whether a tubular strut 340 feet long would be safe against buckling, he has evidently overlooked the twenty years' existence of the Saltash Bridge, which has a tubular arched iron strut 455 feet long, subject to higher stresses than are any of the steel struts in the proposed bridge. Reference is made to the fall of the roof of the Brunswick Theatre, which is attributed to buckling. This accident occurred about fifty-four years ago, and consequently considerably before my time; nevertheless I have heard of it often, and if I am not mistaken, the verdict of the jury was to the effect that the fall of the roof was due to a carpenter's shop weighing about twenty-five tons having been built on the tie-rod, which sagged under the weight, and so pulled the feet of the principals off the wall. However that may be matters little, as engineers are in possession of more recent and trustworthy data than the personal reminiscences of Sir George Airy. American bridges invariably have long struts, and consequently there is no lack of practical experience on the subject.

The late Astronomer Royal thinks that "the proposed construction is not a safe one," and hopes to see it withdrawn. When he wrote his letter it probably did not occur to him that rival railway companies might be only too glad to seize hold of anything which might prejudice the Forth Bridge project and alarm the contractors who were preparing their tenders for the work. I do not complain of Sir George's action, as it involves a matter of taste of which he is sole judge. I would only mention that when he penned the above sentence he had been furnished by the engineers with the Parliamentary evidence and other documents necessary to inform him of the following facts:—(1) That a wind pressure of 448 lbs. per square foot upon the front surface would, as stated in my paper on the Forth Bridge, be "required to upset the bridge, and under this ideal pressure, though the wind bracing would, it is true, be on the point of failing, none of the great tubes or tension members of the main girders would even be permanently deformed." (2) From the evidence given before the Tay Bridge Commissioners, Sir George, being a witness, would know that, even supposing the workmanship had been good, a wind pressure of about one-tenth of the preceding would have sufficed to destroy the Tay Bridge. (3) He would also remember, no doubt, his own report of 1873, wherein he says that "the greatest wind pressure to which a plain surface like that of the Forth Bridge will be subjected in its whole extent is 10 lbs. per square foot." (4) The Parliamentary evidence would have informed him that the proposed design was the outcome of many months' consideration by the engineers-in-chief of the companies interested, representing a joint capital of 225 millions sterling, and that it was referred to a Special Committee of the House of Commons and to a special Committee of the Board of Trade inspecting officers for examination and report, and that the reports of engineers and committees were alike unanimous in testifying to the exceptional strength and stability of the proposed bridge. As a sample of foreign opinion, I would quote that of Mr. Clarke, the eminent American engineer and contractor, who has built more big bridges himself than are to be found in the whole of this country, and who has just completed a viaduct 301 feet in height, by far the tallest in the world. Referring to the proposed bridge, he writes: "If my opinion is of any value I wish to say that a more thoroughly practical and well considered design I have never seen." I need hardly say that the opinion of such a man has far more weight than that of an army of amateurs.

Sir George Airy refers "unhesitatingly to the suspension bridge" as the construction which he should recommend. He has clearly learnt nothing on that head during the past ten years. In a report on the late Sir Thomas Bouch's design for the Forth Bridge on the suspension principle, dated April 9, 1873, he says: "I have no doubt of the perfect access of this bridge, and I should be proud to have my name associated with it." Chiefly on this recommendation, and in spite of numerous warnings from practical men, the bridge was commenced, but it had to be abandoned after spending many thousands, because having reference to the fate of the Tay Bridge, it was pronounced by the Board of Trade and every engineer of experience at home and abroad to be totally unfit to carry railway trains in safety across the Forth.

Sir George Airy stands alone in his advocacy of a suspension bridge for high speed traffic, and in his views as to the force and action of the wind on such a structure. That being so I may be permitted to say that I should have felt no little misgiving if he had approved of the substituted girder bridge, because it has been the aim of Mr. Fowler and myself to design a structure of exceptional strength and rigidity, differing in every essential respect from that with which Sir George evidently would still be proud to have his name associated.

B. BAKER

THE alarming observations in Sir George Airy's paper on the stability of the Forth Bridge as proposed by Mr. Fowler, which appeared in your last issue, seem to call for a reply, and I think I am in a position to make an unbiassed reply, as I had nothing whatever to do with the design, and moreover do not approve of it. I disapprove of the adopted system as one in which the distribution of the material can be economical only in a moderate degree, and I object to it from an æsthetic point of view, and also on account of some practical reasons of minor import, but I have no hesitation in asserting that the material may be so arranged in it—and very probably is so arranged—that the sta-

bility of the bridge when erected would equal that of the best existing structures of that class.

The paper referred to contains six points of objection, which are treated in a general way without attempting a scientific criticism. This is to be regretted considering the importance of the subject. I take each point in succession. With regard to

I. I cannot see an objection to the novelty of a system, if, as n this case, the conditions are unprecedented, and if the author of the paper himself is compelled to recommend a system of striking novelty.

II. What, may be asked, constitutes the enormity of magnitude of a structural part? Is it the excessive proportion of strain in it arising from its own weight to that arising from other weights and forces? If so, it will be found that this proportion may here be still very small, although it may not be ignored, as sometimes is done.

III. The experimental knowledge hitherto derived from structures with rising degrees of magnitude has not upset the theories used in the calculations of strength. It cannot be asserted that the top flange of a common rolled beam, being a strut, we assume twenty times as long as it is wide, would be under a test load in a safer position against buckling than the top flange of the Ohio girder bridge, which is 510 feet long and 20 feet wide, or the bottom flange of the Forth Bridge, which is 675 feet long and from 32 to 120 feet wide.

IV. We constantly rely on the strength of long struts; they exist in all girders, and many of them are of the same importance for the strength of the girders as the links for the strength of a chain. The theory of their strength, imperfect as it is, is applicable to all with a fair amount of truth, and there is no reason why it should not be applied equally to the struts in the Forth Bridge.

V. Assuming that the dangers from wind-pressure during the erection do not concern us here, it would be interesting to hear from the author which parts of the erected bridge would probably give way first, and whether this would take place by crushing, shearing, twisting, or pulling actions. The leverage offered to wind by the long brackets would come into question only when the pressure is different on the two sides of a pier. The difference would produce a twisting action, which would exist in the central pier, but which could be obviated in the two side piers. The resisting leverage of the central pier is 270 feet, or about two-thirds of the acting leverage. Approximately the same proportion obtains with regard to the stability against tilting under uniform wind-pressure, while in the case of the Tay Bridge the proportion was less than one-third.

VI. It is highly improbable that Mr. Baker should not have calculated his struts; in his book on the strength of beams, columns, and arches, he gives a very intelligible deduction of the theory of long struts, which, although elementary and not so elegant as that by the author, seems original. I have found deductions of that kind in most English text books, while in books of foreign origin generally the equation of the line of flexure is taken as the starting point. Its approximate form is—

$$-\frac{M}{EI} = \frac{1}{\rho} = \frac{d^2y}{dx^2}$$

M being the bending moment at any point, E the modulus of elasticity, I the moment of inertia of the section of the strut, and ρ the radius of curvature. The integration gives the limiting weight W acting endways upon a long strut, as already Navier stated it,

$$W = \frac{\pi^2}{a^2} EI$$

where $EI = C$ in the Paper. This formula is not applicable to short struts, since W might exceed the crushing strength of the material. The limiting weight W^1 for short columns is therefore calculated with $W^1 = fp$, where f is the sectional area and p the pressure on the sectional unit. Unfortunately there exists among theorists a difference of opinion as to the proper value of p; some put for it the crushing strength, and others the limit of elasticity, and now and then there are controversies going on about this matter. Meanwhile it is impossible to mark the limit between short and long struts which theoretically exists. Practically, however, the limit is indistinct, and Rankine, Gordon, and others, taking this into consideration, have put the two formulæ together into one empirical formula for W'', the limiting weight for struts of any given dimensions.

$$W'' = \frac{W^1}{1 + \frac{W^1}{W}}$$

This formula embellished with some empirical coefficients gives good results for struts of ordinary proportions, and as the struts in the Forth Bridge seem to have ordinary proportions, it is quite safe to use it for their calculation. M. AM ENDE

3, Westminster Chambers, Victoria Street, S.W., October 24

HAVING read with interest Sir G. Airy's article on this subject in the last number of NATURE, I am glad to see that it advocates a suspension-bridge in lieu of the proposed structure. It may perhaps interest your readers to give the particulars of the Great International Suspension Bridge over the Niagara River, which supports a carriage-way and a railway-track above.

The length of span between the towers is 800 feet. There are 4 cables, each composed of 3640 wires No. 9 = ·155″ diam., without weld or joint; the cables are 10″ in diameter. All the wires of each cable were separately brought into position, so that each one bears its full share of the tension. When a cable had been thus built up, it was tightly served with soft iron wire to bind the 3640 wires together, and to preserve them from rust.

Since this bridge was built, great improvements have been made in the manufacture of wire. Whereas the resistance to tensile stress at the moment of fracture of the best qualities of iron wire, such as that manufactured at Manchester for this bridge, does not much exceed 27 tons per square inch of section, *hardened and tempered steel wire* can now be made in large quantities and in long lengths with a minimum resistance at the moment of fracture of 90 tons per square inch.

Steel plates, rods, or bars cannot be made in quantity with a higher resistance than 34 tons, or less than half that of wire. Hardened and tempered steel wire similar to that used in pianos is thus clearly the most suitable material for suspension bridges, and has been recognised as such in America, where it is to be used in the construction of the New York and Brooklyn suspension bridge, the span of which is the same as the proposed Forth Bridge.

Our English railway engineers, however, have not yet recognised the great advantages wire possesses over any other form of material such as bars, chains, &c., for resisting tensile stress, and the further advantages that wire can be tested more easily and made of a more uniform quality.

Some ten years ago I called on Sir T. Bouch, the former Engineer to the Forth Bridge, to point out the advantages of a tempered steel wire suspension bridge over any other form. of structure for the Forth Bridge. The idea was, however, never worked out on paper. WILLIAM H. JOHNSON

Manchester, October 23

On the Alterations in the Dimensions of the Magnetic Metals by the Act of Magnetisation

I HAVE read with interest Prof. Barrett's paper in NATURE, vol. xxvi. p. 585. Between his results as to the effect of magnetisation on the dimensions of bars of iron, of steel, and of nickel, and those of Sir William Thomson's experiments ("Electrodynamic Qualities of Metals," Part VII., *Phil. Trans.* R. S., Part I., 1879) on the effects of stress in the magnetisation of bars of the same metals, there exists a remarkable analogy, which, however, seems to break down in the case of cobalt. According to these experiments (which, I may mention, were carried out under Sir William Thomson's direction by my brother, Mr. Thomas Gray, and myself), the effect of the application of longitudinal pull to a bar of iron, while under the influence of inductive force tending to produce longitudinal magnetisation, is, for forces lower than a certain critical value, called from the Italian experimenter who first observed it, the Villari Critical Value, to increase, and of the removal of pull, to diminish, the inductive magnetisation. When the magnetising force exceeded the critical value, these effects changed sign, and tended to a constant value as the magnetising force was increased.

Again, the effect of transverse pull, produced by means of hydrostatic pressure in an iron tube, is, when applied, to *diminish* the longitudinal magnetisation, and when removed, to increase it. We see, then, from Joule's result, confirmed by